Robotics Research Technical Report

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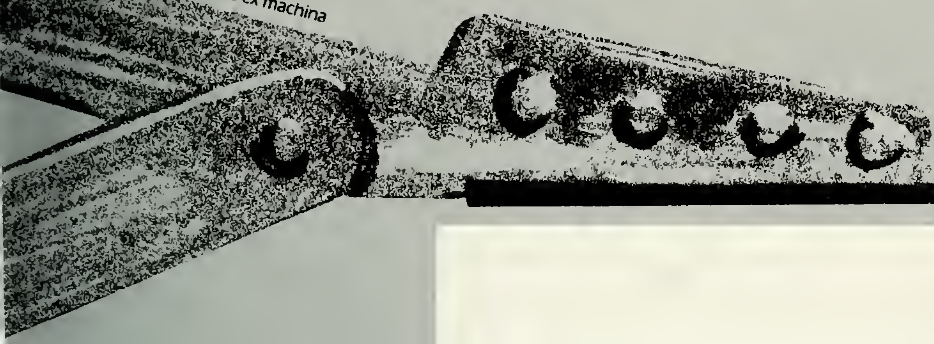

An Initial Finger Design for an Industrial Hand

by

Graham Walker

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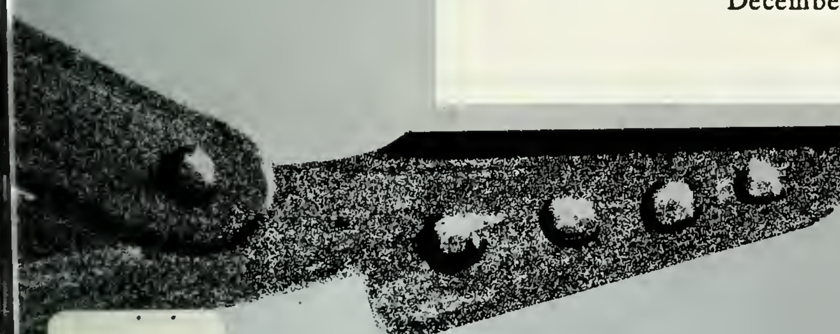

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An Initial Finger Design for an Industrial Hand[1]

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1. Introduction

Robots in their present form have primarily been employed in assembly line type of environments where, for long periods of time, identical sets of parts are continuously placed into identical sets of locations. This reflects limitations of present robots, including limitations of the end effectors presently available for robots. Before the robot can be completely liberated from assembly line tasks, and employed in environments where it may be called upon to perform tasks which cannot be predicted in advance, it will be necessary to develop more flexible end effectors.

In response to this need several groups have developed general purpose hands (e.g. Jacobsen (1984), Salisbury (1982) and Crossley (1977)). In all of these cases the increase in flexibility was achieved, to different degrees, by imitating the human hand. The results were devices which could perform complex manipulations but which required large numbers of actuators and complex control schemes to operate them. In an effort to reduce the complexity of anthropomorphic hands and yet still retain the flexibility required to perform most, if not all, manufacturing tasks, Wright (1985) therefore proposed that a hand should be designed around only the grasps that are required for manufacture. Consequently by eliminating all "non-manufacturing" grips (that can be achieved by the human hand) a simple and yet sufficiently flexible hand could be designed for most industrial needs which would be sufficiently compact to allow it to be a self contained unit capable of being interfaced to most robots and their controllers. The work reported in this paper reflects these ideas of Professor Wright, with whom we are collaborating.

2. Design Procedure

The design objective of the preliminary work reported here is to design and construct as small an industrial hand as possible having joints that can be fully controlled. Our work to date has concentrated on the design of a single finger. In order to meet both the size and control design requirements pneumatic actuators were chosen to operate the hand and in

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particular the Clippard Minimatic sub-miniature single acting cylinders were chosen to operate the finger joints. These cylinders have a piston travel of 6mm, are 31mm long when fully extended and can exert a maximum force of 12N. Two joint designs were considered that used these cylinders to rotate the joints and thereby bend and straighten the finger. The first (Fig. 1(a)) rotated the joint by allowing the cylinder rod to slide along a lever arm whilst the second (Fig. 1(b)) produced the rotation by pinning the cylinder rod to the end of the lever arm. Of these two joint designs the former one was finally rejected because calibration problems would have arisen as a result of the excessive wear that would have occurred between the rod end and the lever arm. By then combining two of these joints a simple finger design could then be produced (Fig. 2) which would have the ability to perform simple tasks, such as rolling a ball.

For a final finger design it is necessary to specify the finger configurations associated with the two extreme cylinder conditions (i.e. fully withdrawn and fully extended). The configurations chosen are such that when both cylinders are fully withdrawn the fist two finger joints will be open by 180^o (Fig. 3(a)) and that when both are fully extended these joints will be bent by 90^o (Fig. 3(b)). This allows the finger to be fully extended or to apply a stable two point grip.

Based solely on these extreme conditions and the cylinder specifications several programs were written to assist in the selection of an optimum finger design.

2.1. The Design Programs

After physical size, the next most important hand characteristics were the maximum grasping force, which was required to be as large as possible, and the manner in which the magnitude of the grasping forces varied with the finger configuration, which was required to be such that the largest grasping forces occur when the hand was almost fully closed.

To completely specify the final finger design it is therefore necessary to find the finger geometry (i.e. the values of α_1 and α_2) which most closely met these secondary requirements. This was done by varying α_1 and α_2 from 0 to 90^o in steps of 5^o to find the geometries that could exert the largest grasping forces (which were related to the piston forces via Equation 1 - the nomenclature associated with this equation can be found in Fig. 4 and 5).

$$f = \left(\frac{4\frac{l_2}{d_2}\sin(\alpha_1+\beta_1+\theta_1)\sin(\alpha_2+\beta_2+\theta_2)}{4\frac{l_2}{l_1}\cos(\theta_2)\sin(\alpha_2+\beta_2+\theta_1)+\frac{d_2}{l_1}\sin(\beta_2)} \right) p_2 \qquad (1)$$

These geometries were then examined in more detail by varying θ_1 and θ_2 from 0 to 90° in steps of 5° and recording the maximum grasping force at each specific finger configuration in order to ascertain were the largest grasping forces would occur for each of these geometries.

From this analysis, it was found that the geometry which could exert the largest grasping force and also in a closed hand configuration had equal joint angles, α_1 and α_2, equal to 5°. From this analysis it was found that the geometry that had both lever arm angles (i.e. α_1 and α_2) equal to 5° could not only exert the largest grasping force but also possessed a good grasping force distribution (i.e. with the largest grasping forces occurring close to the fingers fully closed configuration). However, this geometry proved to be impractical in that in some configurations the moment that could have been exerted by the piston would not have been large enough to overcome the bearing friction. Consequently, this finger geometry was rejected and the next most favourable geometry, which had both lever arm angles equal to 10°, was chosen as the final finger design.

The final finger design has the following characteristics, its working envelope is illustrated in Fig. 6:

first lever arm

angle (α_2)	= 10°
major arm length ($d_2/2$)	= 15.22mm
minor arm length (l_2)	= 5.14mm

second lever arm

arm angle (α_1)	= 10°
major arm length (d_2)	= 30.45mm
minor arm length (l_1)	= 5.14mm

maximum bearing force = 7.5N

maximum grasping force = 3.0N

3. Control of the Actuators

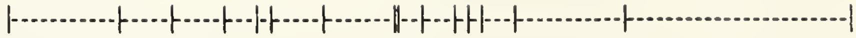
In addition to designing the physical structure of the finger it was also necessary to devise a system which would allow the cylinders in the fingers to be positioned accurately and quickly, whilst also maintaining the desired gripping force. Three systems were considered as possible control schemes for the finger.

The first system would use solenoid valves, which had to have a repeatable opening and closing time, and a pressure reservoir which had a constant pressure equal to the maximum cylinder pressure. Control of the cylinder motion and the force that could be exerted by the cylinder would then be achieved by opening the valve for a sufficient time to allow the required volume of compressed air into or out of the cylinder. This volume would be such that the desired cylinder extension would be achieved via the isothermal expansion of the compressed air: in the case of an empty cylinder the volume of air admitted to the cylinder ($v(t)$) would be a related to the grasping force (f), extension length (l) and supply pressure (p_s) via Equation 2.

$$v(t) = \frac{f.l}{p_s} \tag{2}$$

However, it is uncertain that a solenoid valve could be found that would allow such accurate volume control to be achieved and even if one were found the problems associated with the thermodynamics of unsteady mixing might prove to be so involved that the system would have a very poor response time.

The second system that was proposed was in essence digital and involved employing manifolds that had several (n) ported inlets which were at different pressures then by opening different combinations of inlet valves at the same time it was possible to provide 2^n distinct pressures, up to a pressure which was equal to the maximum inlet pressure. However, not all sequences of inlet pressures could provide 2^n distinct pressure combinations. For example, if the inlet pressures formed an arithmetic series (e.g. 1, 3, 5, 7) there would only be $2n$ available pressure combinations (e.g. for the 1, 3, 5, 7 case these would be 0, 1, 2, 3, 4, 5, 6, 7). Obversely, in the case where all 2^n pressure combinations were available the resulting pressures would not be spaced regularly. For example, in the case of the geometric inlet pressure sequence 1, 2, 4, 8 the available pressure combinations would be 1, $1\frac{1}{2}$, 2, $2\frac{1}{3}$, $2\frac{1}{2}$, 3, $3\frac{2}{3}$, $3\frac{3}{4}$, 4, $4\frac{1}{3}$, $4\frac{1}{2}$, $4\frac{2}{3}$, 5, 6, 8: this irregular pressure spacing is illustrated in the following diagram which shows, from left to right the pressure spacing from 0 to 8.



These phenomena arise from the fact that when several (m) pressures are combined the result is an average of these pressures (Equation 3).

$$\text{Combined pressure } (p_c) = \frac{p_1+p_2+p_3+\ldots\ldots+p_m}{m} \tag{3}$$

In addition, for this scheme to operate correctly it would also be necessary to use solenoid valves which would allow accurate volumes of compressed air to be discharged. This scheme would therefore not only suffer from problems associated with combining pressures but would also suffer from the same problems which were encountered in the first system.

The final system that was examined differed from the other two in that it did not control the cylinder motion via transient discharges but did so by continuously varying the inlet pressure. This was achieved by attaching the cylinder to a pipe that connected a pressure reservoir to an expansion valve (Fig. 7) and then by using the static pressure of the steady compressed air flow operate the cylinder. The static pressure could then be varied by varying the degree to which the valve was open (i.e. varying the total head loss from zero to one). To ensure that the full pressure range (i.e. from zero to the reservoir pressure) was available it would be essential to use either a gate or ball valve since both of these valves (and especially the ball valve) would allow the air to flow freely if the valves were in a fully open position. However, this system does have two flaws in that it uses valves that tend to be relatively large and that the system requires a steady flow of high pressure compressed air.

Of these three control systems, the third alternative appeared to be the most promising, despite its flaws, in that,

a) it would provided continuous control of the hand,

b) it does not need a specific exhaust stage and

c) it can employ valves that do not require precisely timed control signals.

4. Experimental Work

The finger design which was described in section 2.1 has now been built (Fig. 8) and tested . It meets design expectations, except that the spring, in the cylinder that operates the second joint, was found not to be strong enough to return the finger to the straight configuration.

The control scheme illustrated in Fig. 7 has also been tested using a needle valve and an angle valve, in place of the ball valve. In the case of the needle valve it was found that the total head loss is so great that the static pressure changed by only approximately 100mbar (from 6bar) when the valve went from being fully closed to fully open. In the case of the angle valve the static pressure change was found to drop by 2bar (from 6bar) which was an improvement over the needle valve but not enough to take the static pressure down to atmospheric pressure.

5. Future Work

Three changes will shortly be made to the present finger:

a) the present journal bearings will be replaced by ball bearings,

b) the finger will be lightened by using tube to allow the spring in the second cylinder to return the finger the straight configuration and

c) the design of the bearing shafts will be changed so that they can also be used as compressed air inlets to the cylinder blocks.

Longer term efforts will,

a) develop small cylinders that can operate at pressures greater than 10bar, possibly by using composite cylinders,

b) develop ball valves that are small and can easily be controlled by small electric motors and

c) design a hand that employs carbon fibres in its structural members.

6. References

Crossley, F.R.E. and Umholtz, F.G., "Design for a Three-fingered Hand", Mechanism and Machine Theory, Vol. 12, 1977.

Jacobsen, S., Wood, J., Kanutti, D.F. and Biggers, K.B., "The Utah/MIT Dextrous Hand: Work in progress", The International Journal of Robotics Research, 1984, Vol. 3, pp. 21-50.

Salisbury, J.K. and Craig, J.J., "Articulated Hands: Force Control and Kinematic Issues", Robotics Research, Vol. 1, No. 1, 1982, pp. 4-17.

Wright, P.K., "The Design of Sensor Based Robots for Flexible Manufacturing Systems", Proceedings of the 25th International Machine Tool Design and Research Conference, The University of Birmingham, England, 1985, pp. 349-356.

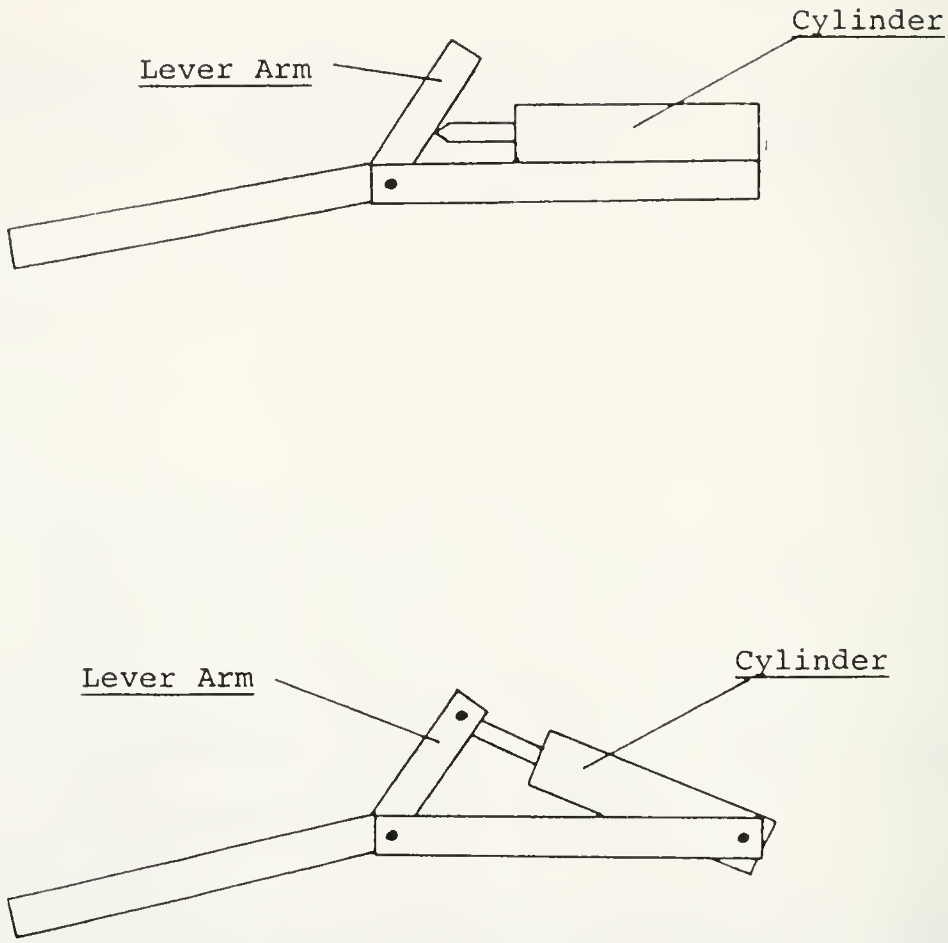


Fig. 1: The two possible finger designs
that employed the miniture cylinders

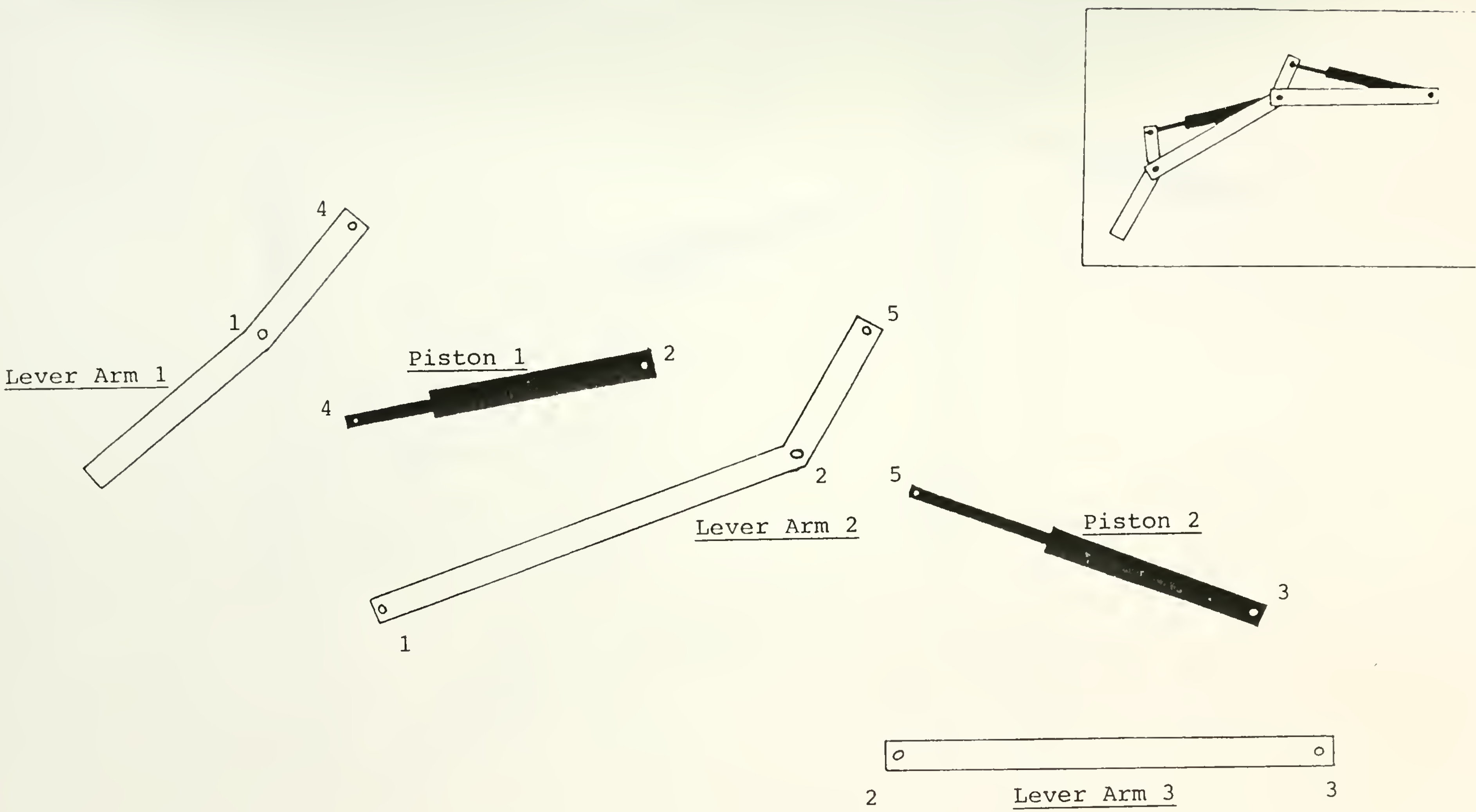


Fig. 2: An exploded schematic of the finger
showing the joint numbers

Fig. 3(a): The finger configuration when both cylinders are fully withdrawn

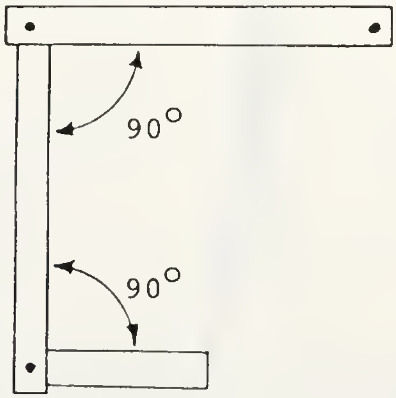


Fig. 3(b): The finger configuration when both cylinders are fully extended

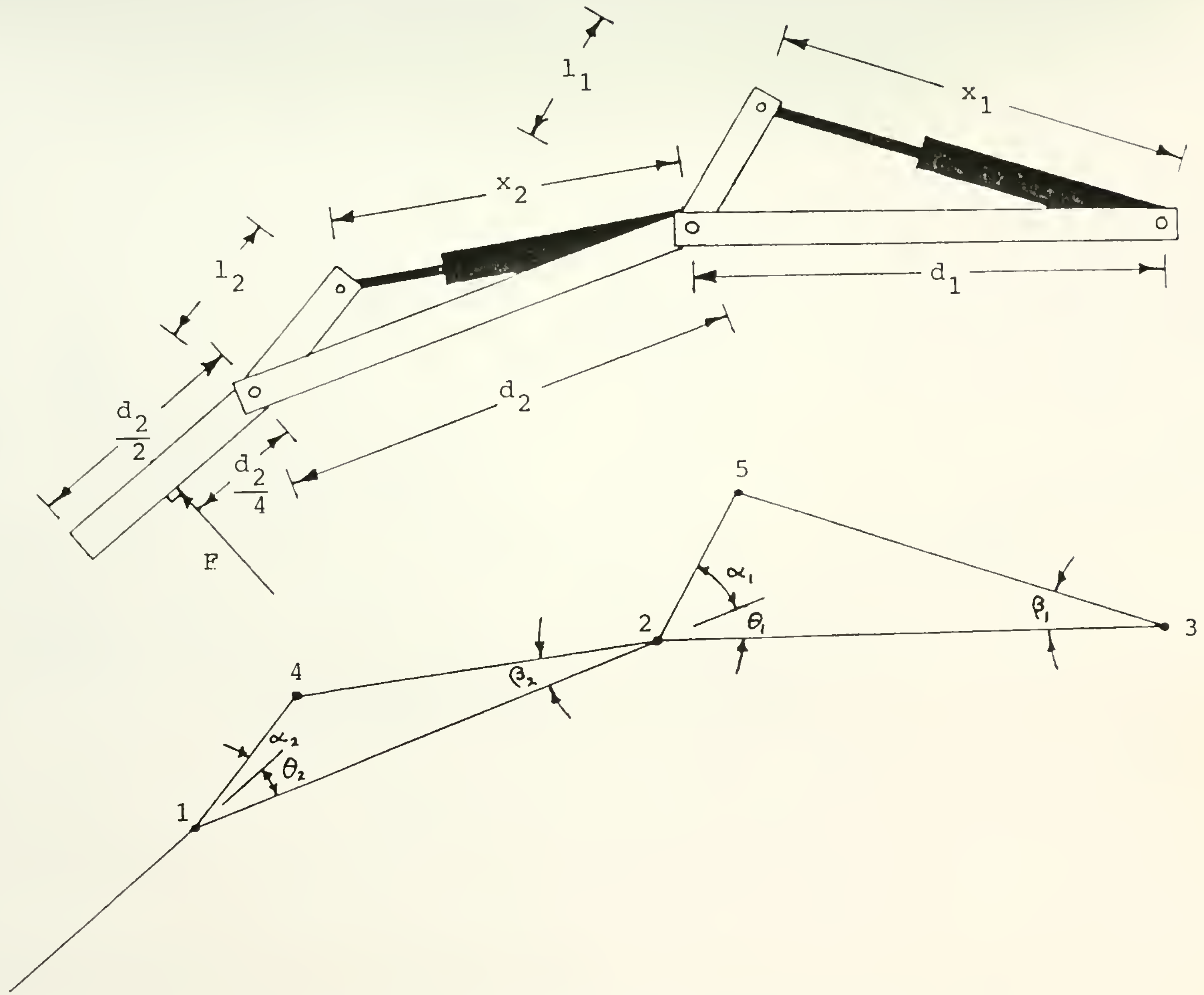


Fig. 4: Length and angle nomenclature

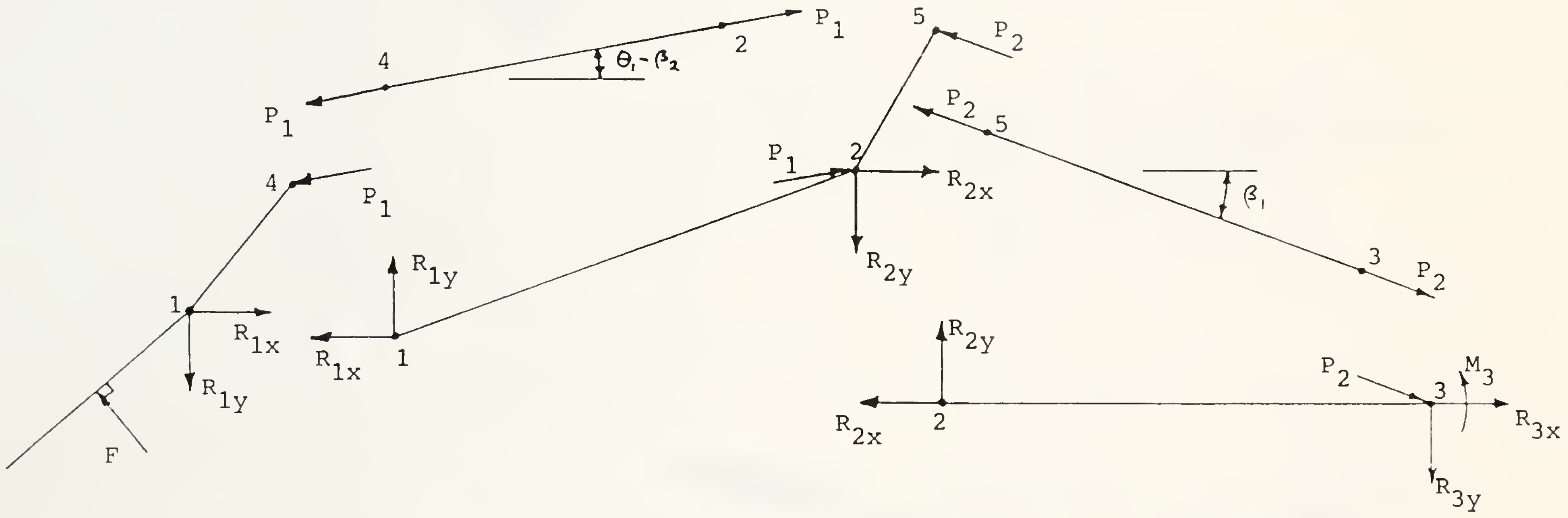


Fig. 5: Force and moment nomenclature

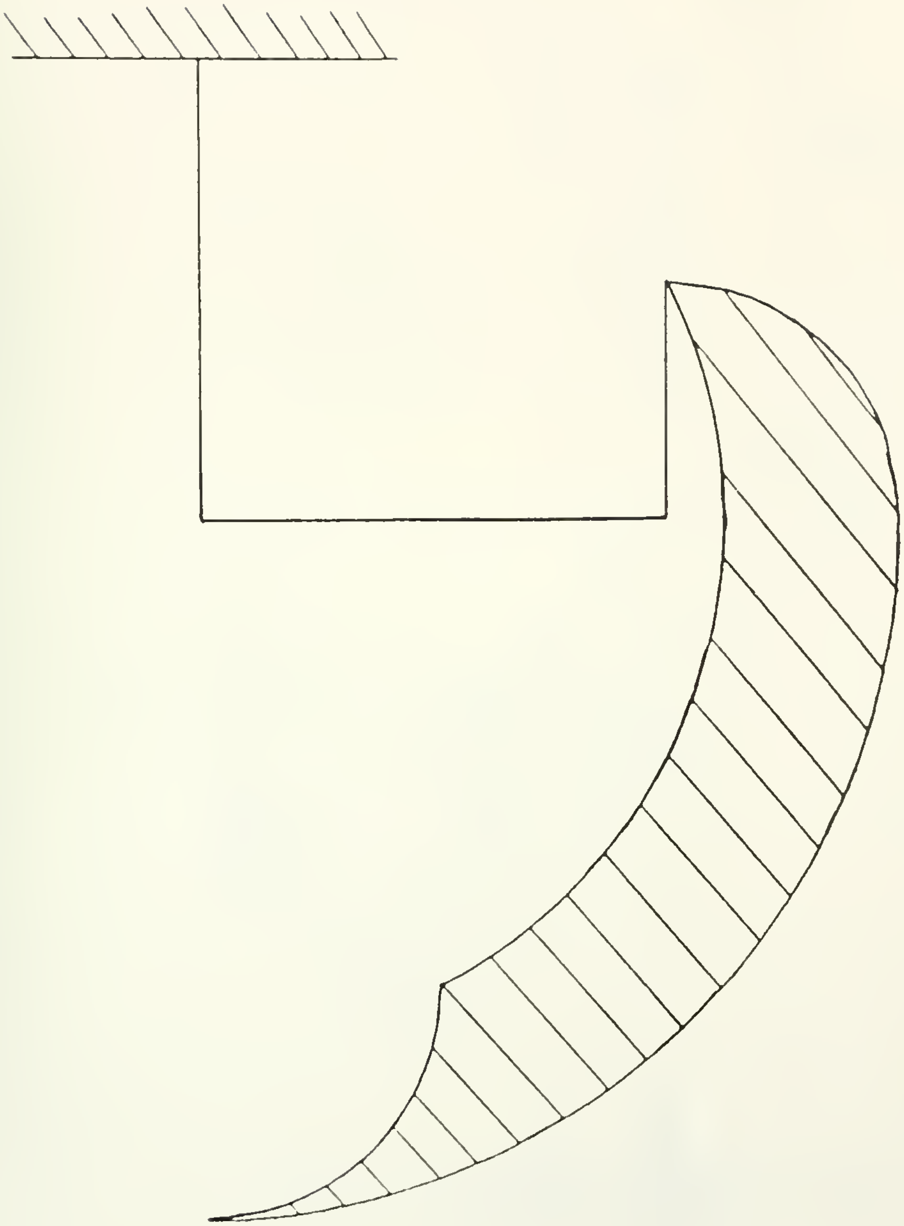


Fig. 6: The working envelope of a $10^{o}, 10^{o}$ finger (twice full scale)

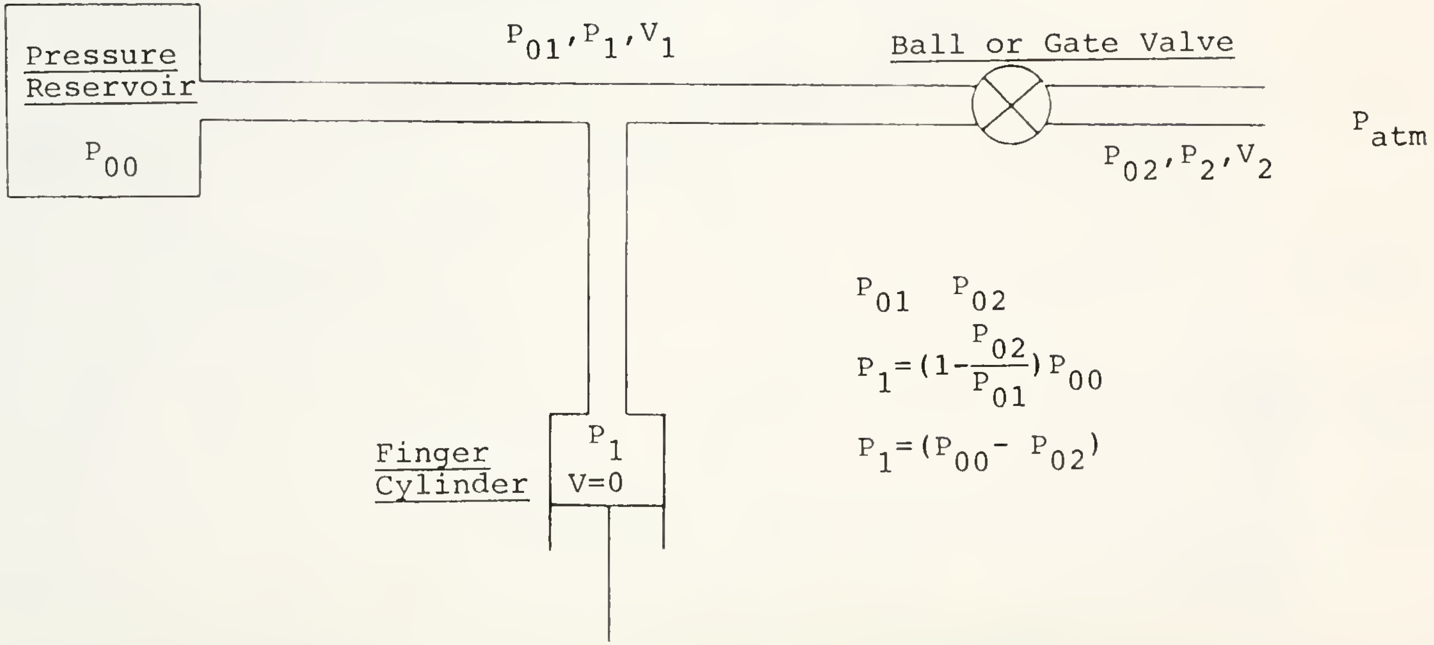


Fig. 7: Actuation scheme for the miniture cylinders

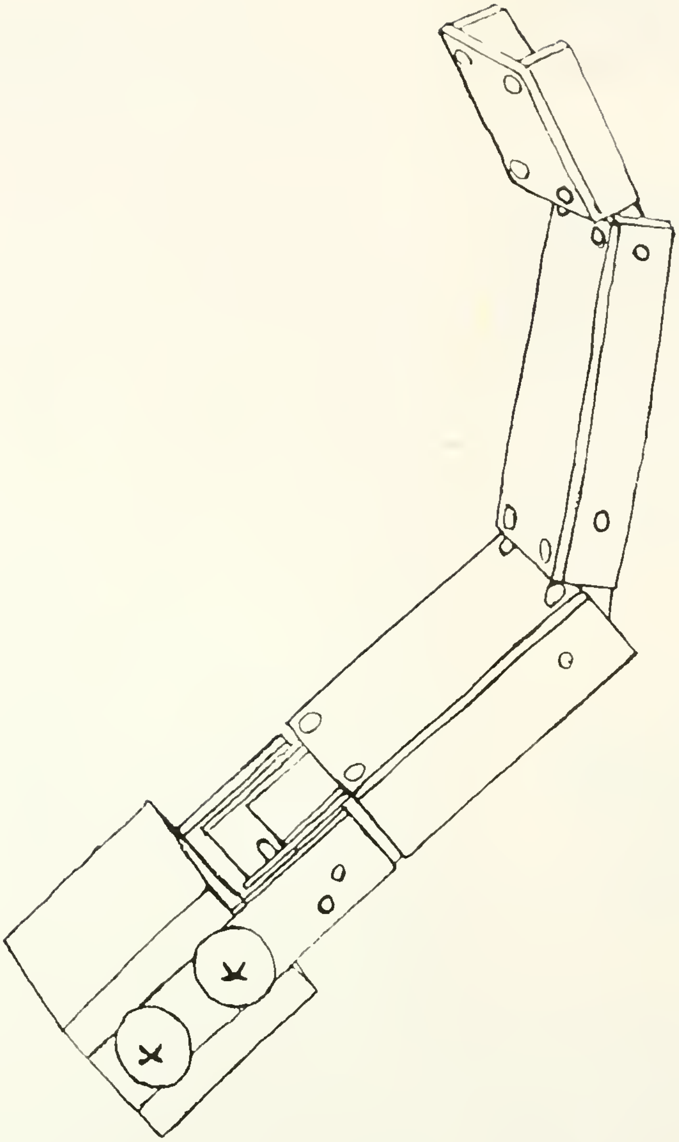


Fig. 8: Isometric drawing of the
assembled finger

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